The Impact of Extreme Weather Events on Consumer Spending[1]

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PRELIMINARY DRAFT. PLEASE DO NOT CIRCULATE!!

Abstract: This paper studies the economic impact of 18 hurricanes that struck the U.S. between 2018 and 2023, using over 6.5 million aggregated and anonymized Mastercard transactions. We use a stacked difference-in-differences approach to estimate changes in consumer spending in hurricane-affected areas. Our analysis finds that hurricanes significantly reduce in-store and online consumer spending and business performance, especially among small, independent businesses. Over a 21-day event period, sales decline by about 1.3 days of average daily sales, with losses concentrated during the hurricane and recovery periods. Independent, small retailers, home improvement stores, and grocery stores are the hardest hit, losing about 1.5 days of average daily sales, while chain stores experience smaller or no net losses due to increases in pre-hurricane spending. In contrast, hotel chains gain around 1.5 days of daily average sales, while gas stations see nearly 2 days of average daily sales gains before the hurricane, though these are offset by later losses. There is no evidence of spending shifting to large online retailers or neighboring areas, except for hotels in nearby locations, which experience increased revenue. Overall, our findings suggest that hurricanes impose permanent losses on small firms in local economies, with limited compensatory shifts in spending.

JEL: G20, G50, D22, O31, Q54

Keywords: Consumer finance; SMEs; Digital Payments; Climate

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1. Introduction

Climate change is driving an increase in extreme weather events (IPCC, 2021). While the long-term economic impacts remain uncertain, projections by U.S. government agencies and international organizations suggest that rising temperatures will negatively affect both GDP levels and growth rates in the coming century (IPCC, 2021; Reidmiller et al., 2017; Kahn et al., 2019; OECD, 2015). For example, a 2017 EPA report estimates that without mitigation efforts, extreme heat could lead to an annual loss of $80 billion in wages by 2090. Historical data further supports these findings, showing that rising temperatures reduce economic productivity, particularly in poorer countries (Dell, Jones, and Olken, 2012; Burke et al., 2015; Diffenbaugh and Burke, 2019).

At the firm level, climate change is also detrimental, with rising temperatures linked to lower productivity (Hugon and Law, 2019; Cevik and Miryugin, 2023) and increased financing challenges (Cevik and Miryugin, 2023; Kling et al., 2021). The growing frequency and intensity of extreme weather events poses additional economic risks to household consumption and business performance. Studies across both developing and developed countries show that extreme weather events negatively affect consumption (Bui et al., 2014; Gallagher and Hartley, 2017; Deryugina et al., 2018), especially among poorer households (Van den Berg and Burger, 2008; Sawada and Shimizutani, 2008). Businesses also experience losses during extreme weather events, including sales declines (Beatty et al., 2019; Aladangady et al., 2017; Agarwal et al., 2021), increased delinquencies, and tighter credit, especially for small firms (Basker and Miranda, 2017; Collier et al., 2019; Baltas et al., 2021).

This paper analyzes the economic impact of 18 hurricanes, ranging from Category 1 to Category 5, that struck the continental United States between 2018 and 2023. Using a stacked difference-in-differences regression approach, we examine over 6.5 million anonymized consumer debit and credit card transactions to track digital sales in both physical stores and online in hurricane-affected areas. Our analysis focuses on consumer spending during the preparation, impact, and recovery periods. Unlike previous studies using household-level or aggregated data, our study provides a more granular view of business performance, covering small independent businesses, chain stores, and large online retailers.

We hypothesize that consumer spending patterns change during the hurricane lifecycle. In the days leading up to a hurricane, consumers are likely to prepare by increasing spending on

essentials such as food and gas. However, during the storm, high winds and hazardous driving conditions might limit in-person shopping and disrupt store deliveries. In the post-hurricane recovery period, spending might rebound as consumers address immediate needs and restock supplies.

Our analysis shows that hurricanes significantly reduce both in-store and online consumer spending and business performance, particularly for small, independent businesses. While spending temporarily increases by about one-fifth of an average day's sales during the preparation period, overall net losses amount to 1.4 days of average daily sales over the event period. Independent restaurants, retailers and grocery stores suffer greater losses than chain stores. For example, chain restaurants have no net losses, while independent restaurants suffer about a day's average daily sales. Hotel chains, however, benefit, gaining 1.5 days of average daily sales.

We also explore the possibility of spending substitution by local residents—whether consumers shift purchases to large online retailers or neighboring areas within 50 km of the hurricane zone. However, our findings show a net decline in sales at large online retailers of about 0.8 days. There is little evidence of consumers shifting spending to neighboring areas, except for increased sales at gas stations and hotels outside the hurricane-affected zones. *[[Regression results checking if spending shifts to cash, as measured by ATM cash withdrawals, is forthcoming.]]*

As climate related events increase in frequency and severity[2], our analysis points to permanent losses to local affected economies, with no evidence of spending substitution to online or neighboring firms.

2. Data

Our dataset consists of anonymized daily merchant-level transactions from hurricane-affected areas.[3] The boundaries of these areas are identified using data from the National Oceanic and Atmospheric Administration (NOAA) National Hurricane Center GIS Archive[4]. We supplement this data with location information to aggregate transactions made by residents at hurricane-affected zip-codes, including both in-store and online purchases. The analysis covers hurricanes

[2] For example, the 2024 hurricane season "defying forecasts". See: https://www.cnn.com/2024/09/06/weather/hurricane-season-atlantic-storms-climate/index.html.
[3] The payment provider whose data forms the basis of our research applied robust privacy and data protection controls.
[4] Data is available at: https://www.nhc.noaa.gov/gis/archive_besttrack.php.

from 2018 to 2023, with data for the active 2024 hurricane season to be added in November. Firms are categorized by size (independent or chain stores) and sector. Hurricanes are identified as category 1 to 5.

3. Methodology

We analyze the effect of hurricanes on the sales of merchants located within hurricane affected areas using a stacked difference-in-differences regression approach. Merchants affected by other hurricanes in other hurricane seasons act as the control group. We further exclude zip-codes within 500km distance from the outbound of the hurricane path from the control group. For each hurricane event, we consider 15 days before and after the arrival of a hurricane as the event window. The same approach applies to the consumer level analysis, except that the consumer zip-code is used as location identifier instead of merchant zip-code. We also conduct analysis on the effect of hurricane on the sales of merchants located in neighboring areas, defined as 50km from the outbound of the hurricane affected areas but not on the hurricane path in the subsequent days.

We divide the data into four time periods:

1. **Pre-event**: Seven to six days before the hurricane (used for pre-trend analysis)
2. **Forecast**: Five days before the hurricane
3. **Hurricane**: The day of the hurricane and four days immediately after
4. **Recovery**: Five to 15 days after the hurricane

We estimate the following equation:

$$\ln(1 + Y_{it}) = \beta_1 Pre - \text{event}_t \times D_i + \beta_2 Forecast_t \times D_i + \beta_3 Hurricane_t \times D_i + \beta_4 Recovery_t \times D_i + \alpha_i + \gamma_t + \epsilon_{it}$$

where Y_{it} is the total in-store and online transaction value for local merchant i on day t, D_i is a dummy variable indicating a treated area, and α_i and γ_t represent zip-code and day fixed effects. The coefficient β_3 measures the impact of the hurricane, while β_1 reflects pre-trends, β_2 mesures the forecast period, and β_4 measures recovery effects. We also estimate the model by industry, firm size, and hurricane intensity.

To illustrate business sales dynamics in response to multiple hurricanes we estimate:

$$\ln(1 + Y_{it}) = \sum_{s=-21}^{11} \beta_s T_t \times D_i + \alpha_i + \gamma_t + \epsilon_{it} \quad (2)$$

where β_s measures the difference in business sales between the treatment and control cities on each day before and after the start of hurricane (s=0). We also estimate this model by industry, firm size, and hurricane intensity.

4. Results

Our analysis finds significant impacts of hurricanes on consumer spending and business performance, especially at small, independent businesses.

The pre-trend analysis shows no significant difference between treatment and control areas, confirming that these areas were comparable before the hurricanes occurred.

We find that consumer spending drops significantly because of the hurricane, in terms of both the value of daily in-store and online transactions at local businesses and the number of daily transactions (Table 1, Panel A, Columns 1-2). We aggregate the net impact on firm sales by multiplying the size of the impact on average daily sales (β) by the number of days in the period. For example, while sales increase by about one-fifth of an average day's sales during the preparation period, spending declines by 1.4 days of average daily sales during the hurricane and immediately afterward, with an additional fifth of a day's sales lost during the recovery phase (Table 1, Panel B). This amounts to a total loss of approximately 1.5 days of average daily sales over the 21-day event period, with a similar decline observed in transaction volume. These results are illustrated in Figure 1, panel A.

We also examine potential substitution effects, such as consumers shifting spending to large online retailers or neighboring areas (Table 1, columns 3-4). Large online retailers lose about 0.85 days of sales during the pre-hurricane and impact periods, likely due to concerns over delivery disruptions, and there is no notable increase in online spending during the recovery phase. Moreover, we find no significant change in spending in neighboring areas outside the hurricane-affected zone. These results are illustrated in Figure 1, panels B and C.

Consumers in areas hit by high-intensity hurricanes (Categories 4 and 5) show a significant increase in spending during the pre-hurricane period, followed by a sharper decline during the hurricane and recovery phases (Figure 2). However, when averaged across the entire event period, there is no significant difference in overall spending between high- and low-intensity hurricanes.

Industry-specific findings highlight variations between independent establishments and chain stores (Figure 3).[5] Retail firms lose about 3.5 days of sales in the 15 days following the hurricane, but the pre-hurricane spending surge mitigates these losses, resulting in a net decline of around 1 day of sales. Independent retailers face steeper losses—about 1.5 days of sales—compared to chain retailers, which lose only half a day of sales (Figure 4). Local grocery chains show no net losses due to substantial pre-hurricane spending, while independent grocery stores experience a net loss of around 0.85 days of sales. Similarly, chain restaurants and home improvement stores see no significant losses, but independent stores in both sectors lose about a day's worth of sales.

Hotel chains, in contrast, benefit from hurricanes, gaining around 1.5 days of sales during the hurricane period, with the largest increase occurring during the recovery phase. Hotel bookings online and in neighboring areas also increase by an average of 1.3 and 2.6 days of sales, respectively. Gas stations see nearly 2 days of pre-hurricane sales gains as consumers prepare for potential evacuations by filling up their vehicles, but these gains are offset by losses during the hurricane and recovery periods, leading to a net loss. Gas stations in neighboring areas, however, benefit, with pre-event sales increasing by about one-third of a day's revenue, especially during Category 4 and 5 hurricanes, where sales rise by half a day during the preparation period and a full day during recovery.

5. Conclusion

Using a dataset of anonymized and aggregated daily merchant-level transaction data, we identify hurricanes as an instrument for unexpected income shocks to assess their causal impact on local economies and business activity. Our findings indicate a net loss to the local economy, particularly for smaller, independent businesses, with no significant increase in spending at large online retailers or in neighboring areas. Even in the context of a high-income country, the effects of extreme weather events are substantial. Consumer spending in hurricane-affected areas declines by nearly 1.4 days of average daily sales over the 21-day event period, especially impacting small, independent firms across most major industries. Although our analysis is based on the prevalence of digital merchant payments in the United States, these insights may be valuable for other countries facing climate-related disasters. As the frequency and severity of extreme weather events are forecasted to rise, our study underscores the potential economic consequences for small businesses in affected communities.

[5] Regression results by industry are shown in Annex A.

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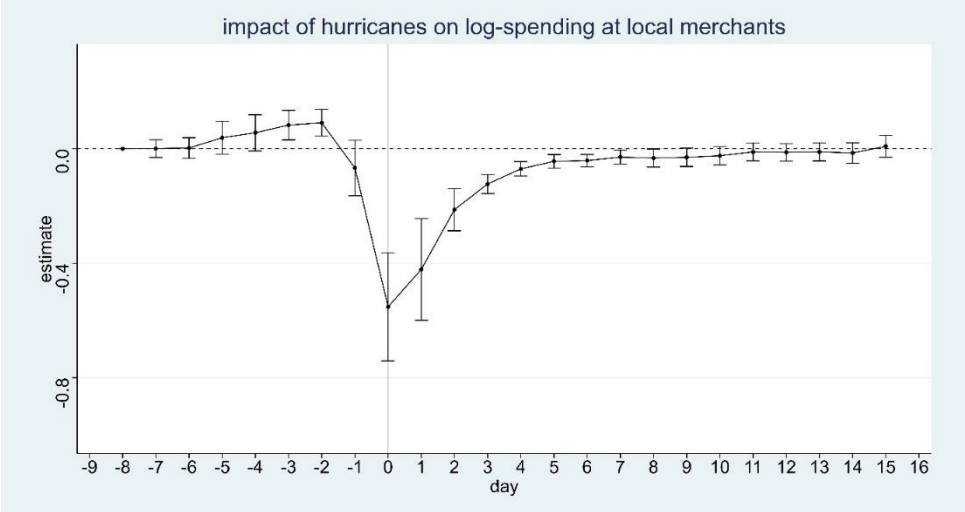
Table 1: The impact of hurricanes

	(1) Total sales (log)	(2) Number of Transaction (log)	(3) Online volume (log)	(4) 0-50km away (log)
Panel A: overall effect				
Pre-hurricane (-7,-6)	-0.0019 (0.0145)	-0.0076 (0.0173)	0.0030 (0.0154)	0.0406 (0.0618)
Post-hurricane announcement (-5 to 15)	-0.0624*** (0.0134)	-0.0787*** (0.0143)	-0.0346** (0.0108)	-0.0337 (0.0492)
Panel B: effect by stage				
Pre-hurricane (-7,-6)	0.0020 (0.0142)	-0.0034 (0.0171)	0.0030 (0.0153)	0.0409 (0.0617)
Post-hurricane announcement (prep) (-5,-4,-3,-2,-1)	0.0432* (0.0184)	0.0344 (0.0187)	-0.0321* (0.0139)	0.0329 (0.0519)
Hurricane (impact) (0 to 4)	-0.2721*** (0.0410)	-0.2992*** (0.0427)	-0.1125*** (0.0177)	-0.0409 (0.0549)
Post-hurricane (recovery) (5 to 15)	-0.0217* (0.0089)	-0.0366*** (0.0100)	-0.0047 (0.0101)	-0.0592 (0.0529)
Merchant zip-code fixed effects	Yes	Yes	Yes	Yes
Date fixed effects	Yes	Yes	Yes	Yes
Observations	3,724,620	3,724,514	2,975,284	1,485,488

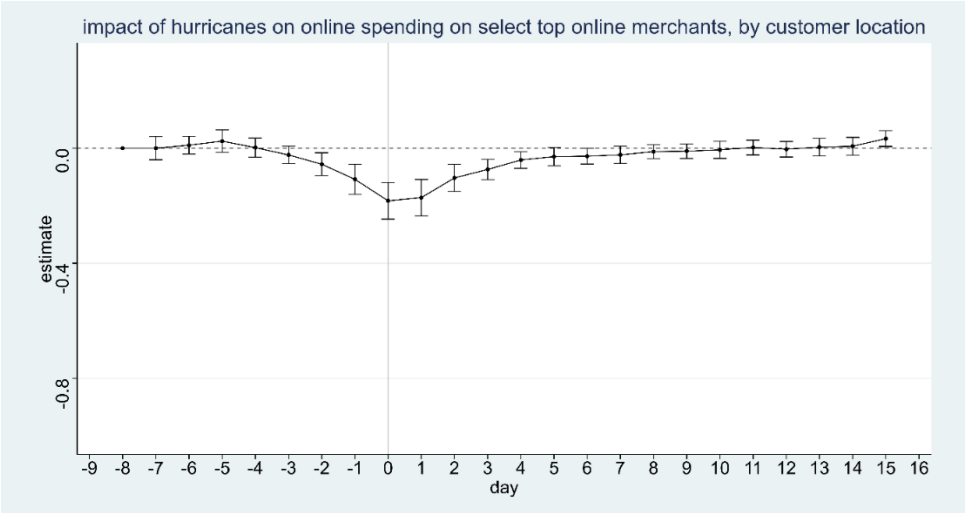
Notes: The table presents the estimates on the effect of hurricane on business transactions in the hurricane-affected zones during the pre- and post-hurricane period, relative to the other hurricane-prone but non-affected counterparts. The dependent variable is the natural logarithm of a merchant's daily transaction plus one. In Panel A, *Pre-hurricane* is defined as the 3-day period before the hurricane forecast has been issued, and *Post-hurricane* announcement is the aggregated days during the preparation, impact, and recovery periods.. In Panel B, *Post-hurricane announcement (prep)* refers to the days before the landfall of hurricane but after forecast has been issued. *Hurricane (impact)* refers to the days when the hurricane is active. *Post-hurricane (recovery)* refers to a 5-day periods after the hurricane subsides. The dependent variables are as follows: column (1) is log total consumer spend at local merchants in-store and online; column (2) is the log number of transactions at local businesses, in-store and online; column (3) is the log online spend of consumers living within the hurricane band at large online retailers; column (4) is the log total spend in-store and online of consumers living in the hurricane band at stores which are 0-50 kilometers outside the hurricane band. Standard errors in parentheses are two-way clustered by zip-code and transaction date. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Figure 1: Event study

(a) Consumer spending at local merchants



(b) Consumer spending by residents within the hurricane band, at large online retailers



(c) Consumer spending by residents within the hurricane band, at retailers 0-50 km outside the hurricane area

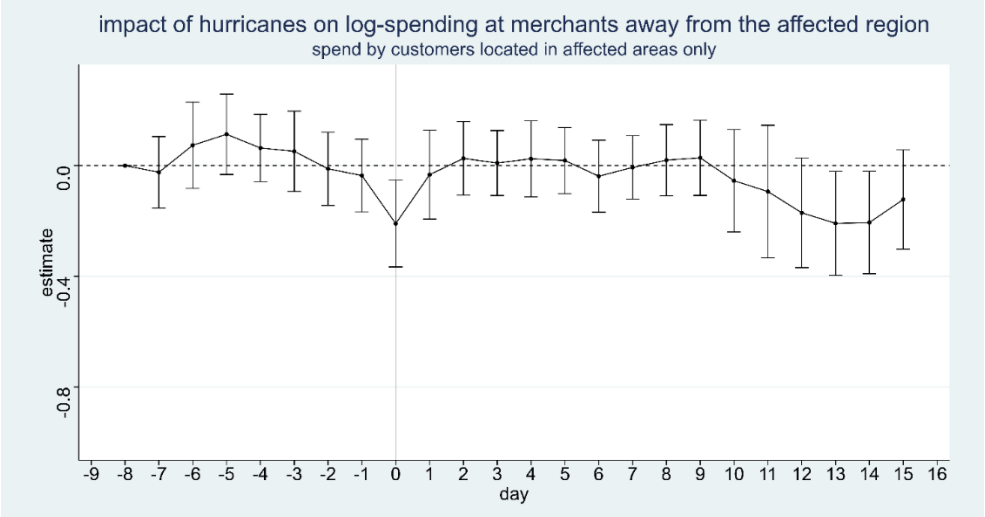


Figure 2: Heterogeneous effects, by hurricane intensity

a. Consumer spending at local merchants, by hurricane intensity

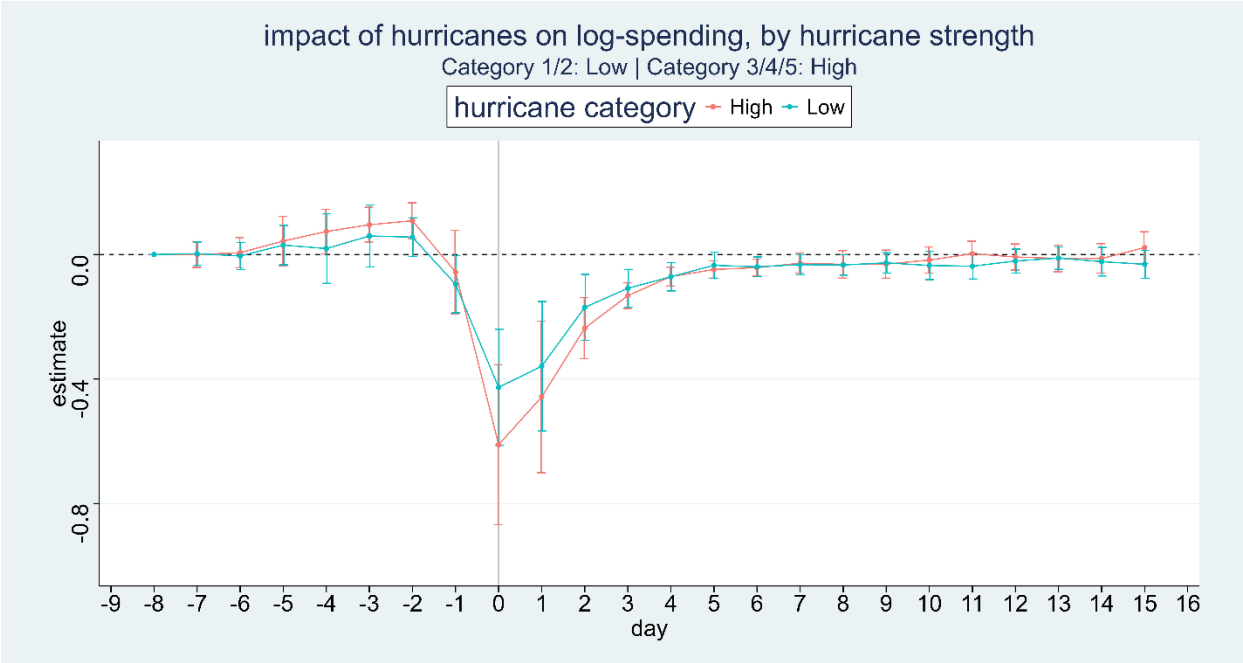
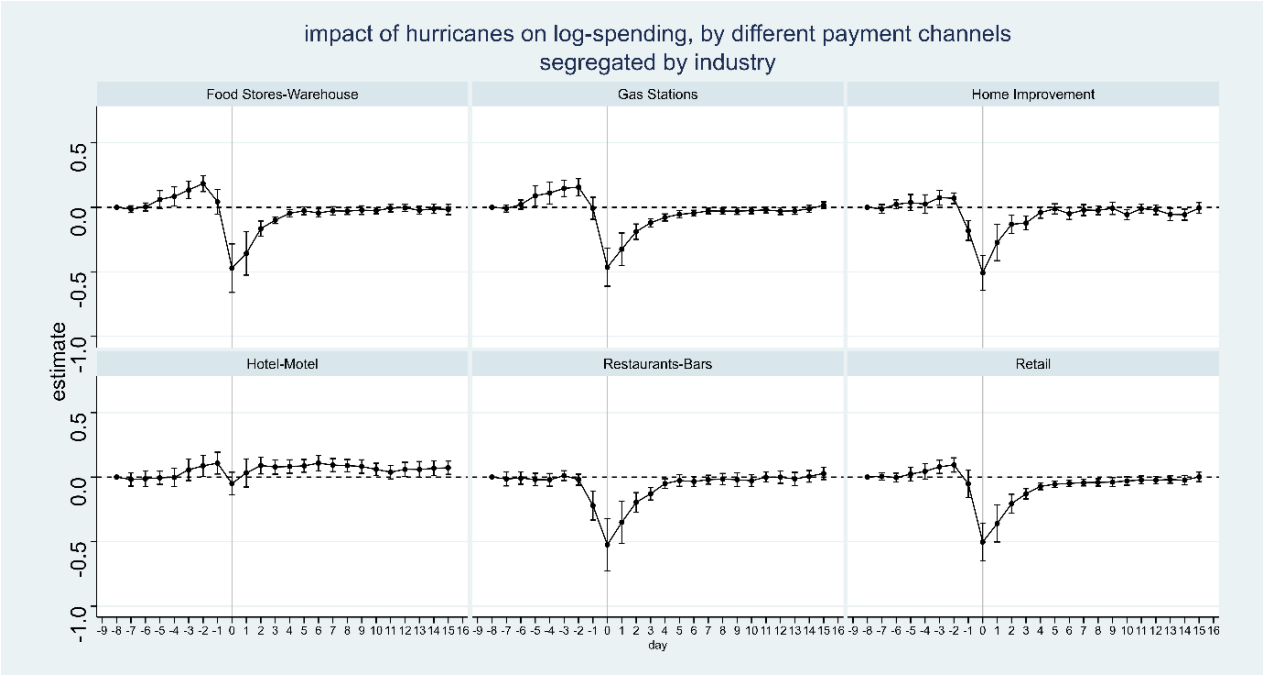
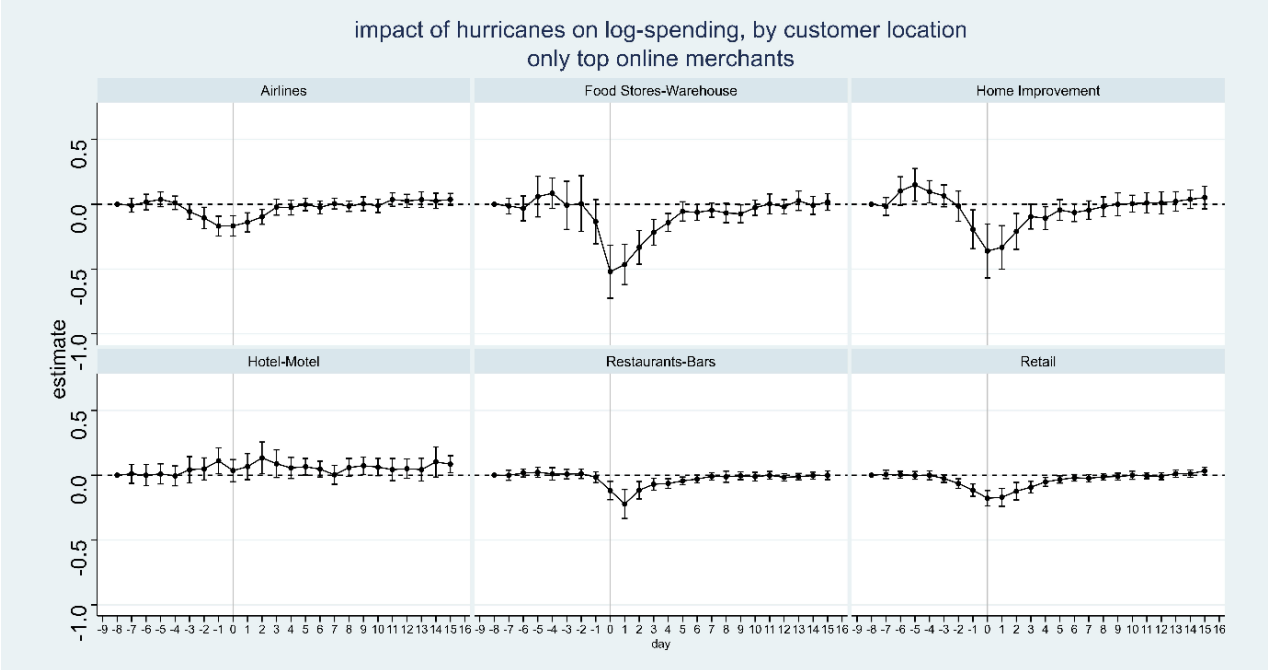


Figure 3: Hurricane impact, by sector

a. Spending at local merchants



b. Spending on Online Merchants



c. Consumer spending by residents within the hurricane band, at retailers 0-50 km outside the hurricane area

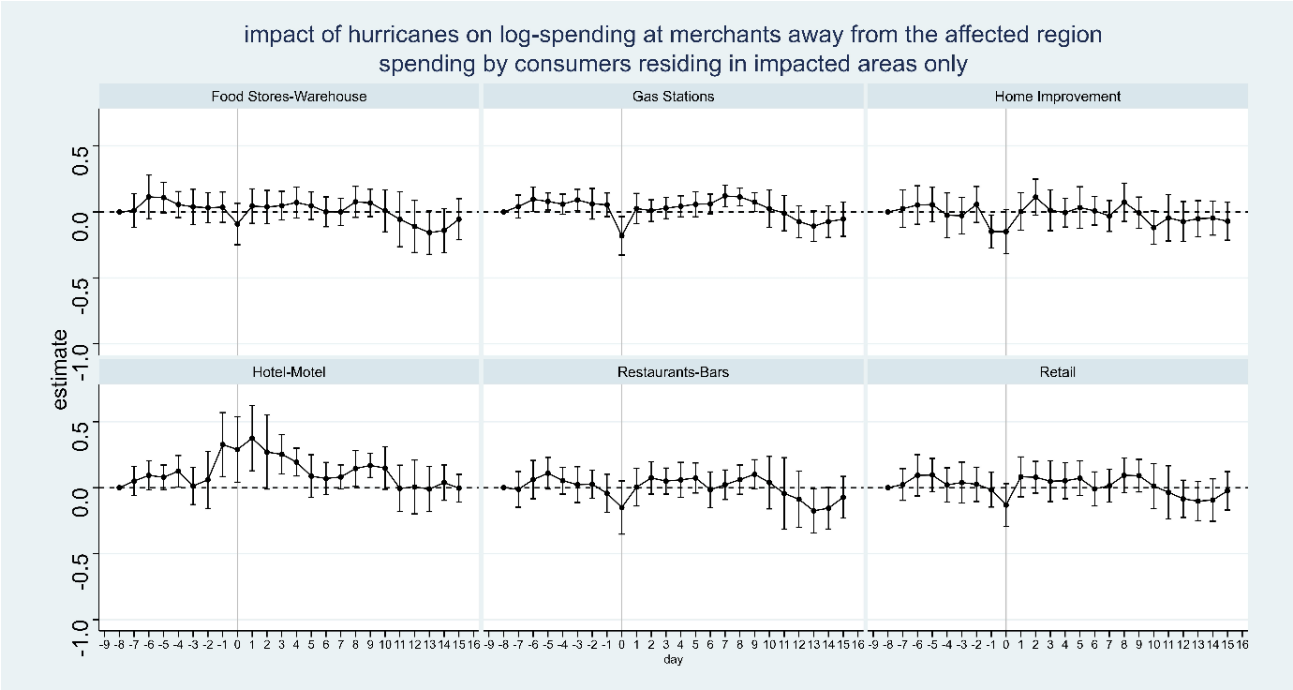
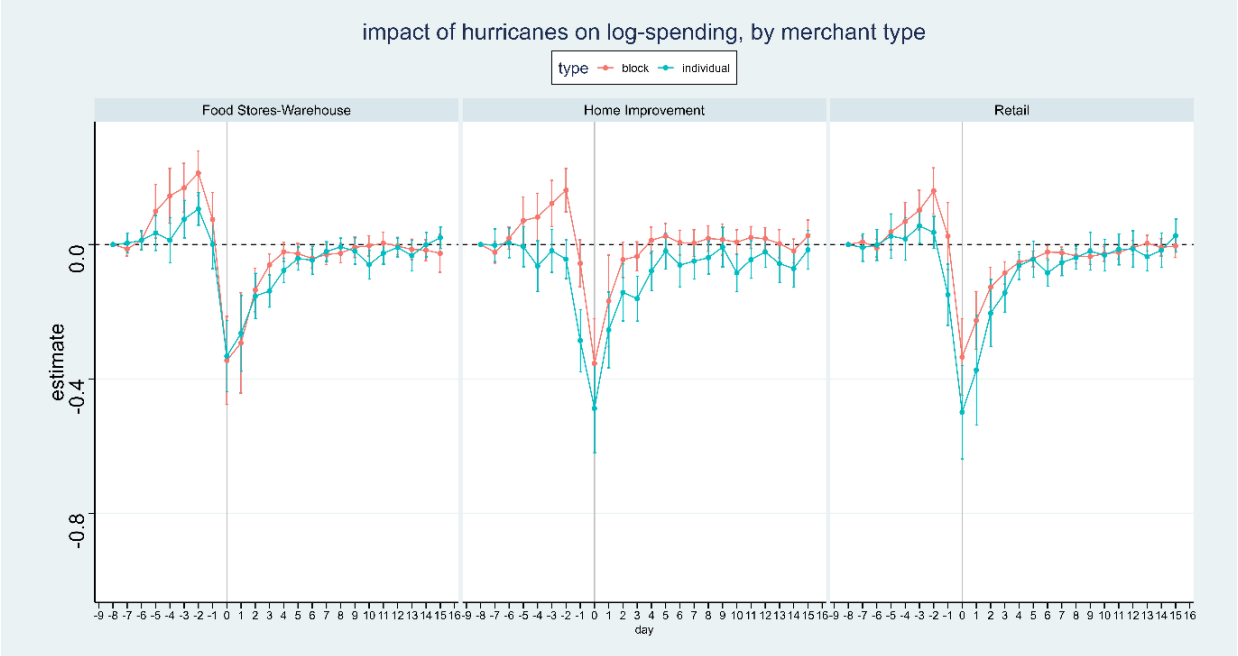


Figure g4: Heterogeneous effects, by industry and firm size

a. Consumer spending at local merchants, by firm size and select sectors



Annex A: Regression results, by Sector

b. Restaurant-bars

	(1) Total sales (log)	(2) Independent store sales (log)	(3) Chain store sales (log)
Panel A: overall effect			
Pre-hurricane (-7,-6)	-0.0093 (0.0120)	0.0048 (0.0128)	-0.0074 (0.0108)
Post-hurricane announcement (-5 to 15)	-0.0372** (0.0128)	-0.0419** (0.0132)	-0.0148 (0.0135)
Panel B: effect by stage			
Pre-hurricane (-7,-6)	-0.0034 (0.0122)	0.0088 (0.0129)	0.0012 (0.0108)
Post-hurricane announcement (prep) (-5,-4,-3,-2,-1)	0.1041*** (0.0212)	0.0476* (0.0192)	0.1411*** (0.0227)
Hurricane (impact) (0 to 4)	-0.2227*** (0.0367)	-0.1901*** (0.0257)	-0.1634*** (0.0314)
Post-hurricane (recovery) (5 to 15)	-0.0223* (0.0087)	-0.0211 (0.0117)	-0.0201 (0.0106)
Merchant zip-code fixed effects	Yes	Yes	Yes
Date fixed effects	Yes	Yes	Yes
Observations	**2,631,007**	**2,728,561**	**1,529,859**

c. Home Improvement

	(1) Total sales (log)	(2) Independent store sales (log)	(3) Chain store sales (log)
Panel A: overall effect			
Pre-hurricane (-7,-6)	0.0028 (0.0133)	-0.0008 (0.0201)	-0.0052 (0.0140)
Post-hurricane announcement (-5 to 15)	-0.0574*** (0.0142)	-0.0862*** (0.0191)	-0.0003 (0.0148)
Panel B: effect by stage			
Pre-hurricane (-7,-6)	0.0054 (0.0136)	-0.0008 (0.0203)	-0.0015 (0.0140)
Post-hurricane announcement (prep) (-5,-4,-3,-2,-1)	0.0078 (0.0205)	-0.0799*** (0.0237)	0.0772*** (0.0219)
Hurricane (impact) (0 to 4)	-0.2056*** (0.0329)	-0.2145*** (0.0324)	-0.1124*** (0.0307)
Post-hurricane (recovery) (5 to 15)	-0.0288* (0.0120)	-0.0423* (0.0184)	0.0102 (0.0131)
Merchant zip-code fixed effects	Yes	Yes	Yes
Date fixed effects	Yes	Yes	Yes
Observations	**1,782,475**	**1,794,253**	**1,059,113**

b. Retail

	(1) Total sales (log)	(2) Independent store sales (log)	(3) Chain store sales (log)	(4) Large online retailer sales (log)	(5) 0-50km away sales (log)
Panel A: overall effect					
Pre-hurricane (-7,-6)	-0.0021 (0.0144)	-0.0086 (0.0198)	-0.0042 (0.0107)	0.0034 (0.0131)	0.0018 (0.0726)
Post-hurricane announcement (-5 to 15)	-0.0611*** (0.0116)	-0.0700*** (0.0177)	-0.0266** (0.0097)	-0.0381*** (0.0094)	-0.0295 (0.0516)
Panel B: effect by stage					
Pre-hurricane (-7,-6)	0.0021 (0.0143)	-0.0059 (0.0199)	0.0006 (0.0102)	0.0031 (0.0129)	0.0021 (0.0725)
Post-hurricane announcement (prep) (-5,-4,-3,-2,-1)	0.0404* (0.0179)	-0.0012 (0.0215)	0.0806*** (0.0185)	-0.0414** (0.0127)	0.0199 (0.0566)
Hurricane (impact) (0 to 4)	-0.2471*** (0.0336)	-0.2500*** (0.0377)	-0.1586*** (0.0228)	-0.1209*** (0.0180)	0.0009 (0.0618)
Post-hurricane (recovery) (5 to 15)	-0.0307*** (0.0087)	-0.0282 (0.0158)	-0.0207** (0.0072)	-0.0037 (0.0083)	-0.0635 (0.0535)
Merchant zip-code fixed effects	Yes	Yes	Yes	Yes	Yes
Date fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	**2,853,140**	**2,638,671**	**2,393,467**	**2,927,606**	**846,765**

c. Hotel-Motels

	(1) Total sales (log)	(2) Independent store sales (log)	(3) Chain store sales (log)	(4) Large online retailer sales (log)	(5) 0-50km away sales (log)
Panel A: overall effect					
Pre-hurricane (-7,-6)	-0.0128 (0.0238)	-0.0065 (0.0271)	-0.0175 (0.0217)	0.0072 (0.0296)	0.0604 (0.0496)
Post-hurricane announcement (-5 to 15)	0.0622** (0.0190)	0.0629** (0.0208)	0.0715*** (0.0183)	0.0583* (0.0239)	0.1248*** (0.0372)
Panel B: effect by stage					
Pre-hurricane (-7,-6)	-0.0133 (0.0238)	-0.0075 (0.0271)	-0.0179 (0.0217)	0.0065 (0.0296)	0.0607 (0.0495)
Post-hurricane announcement (prep) (-5,-4,-3,-2,-1)	0.0508* (0.0250)	0.0401 (0.0267)	0.0624* (0.0242)	0.0425 (0.0299)	0.1257* (0.0501)
Hurricane (impact) (0 to 4)	0.0446 (0.0267)	0.0429 (0.0262)	0.0570* (0.0264)	0.0732** (0.0280)	0.2794*** (0.0601)
Post-hurricane (recovery) (5 to 15)	0.0737*** (0.0191)	0.0799*** (0.0212)	0.0809*** (0.0184)	0.0587* (0.0251)	0.0613 (0.0403)
Merchant zip-code fixed effects	Yes	Yes	Yes	Yes	Yes
Date fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	**1,287,835**	**935,143**	**914,065**	**1,288,241**	**238,283**

d. Grocery stores

	(1) Total sales (log)	(2) Independent store sales (log)	(3) Chain store sales (log)	(4) Large online retailer sales (log)	(5) 0-50km away sales (log)
Panel A: overall effect					
Pre-hurricane (-7,-6)	-0.0093 (0.0120)	0.0048 (0.0128)	-0.0074 (0.0108)	-0.0289 (0.0319)	0.0641 (0.0643)
Post-hurricane announcement (-5 to 15)	-0.0372** (0.0128)	-0.0419** (0.0132)	-0.0148 (0.0135)	-0.0851*** (0.0227)	0.0046 (0.0398)
Panel B: effect by stage					
Pre-hurricane (-7,-6)	-0.0034 (0.0122)	0.0088 (0.0129)	0.0012 (0.0108)	-0.0244 (0.0314)	0.0646 (0.0641)
Post-hurricane announcement (prep) (-5,-4,-3,-2,-1)	0.1041*** (0.0212)	0.0476* (0.0192)	0.1411*** (0.0227)	0.0045 (0.0429)	0.0606 (0.0438)
Hurricane (impact) (0 to 4)	-0.2227*** (0.0367)	-0.1901*** (0.0257)	-0.1634*** (0.0314)	-0.3254*** (0.0435)	0.0337 (0.0470)
Post-hurricane (recovery) (5 to 15)	-0.0223* (0.0087)	-0.0211 (0.0117)	-0.0201 (0.0106)	-0.0268 (0.0198)	-0.0311 (0.0440)
Merchant zip-code fixed effects	Yes	Yes	Yes	Yes	Yes
Date fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	**2,631,007**	**2,728,561**	**1,529,859**	**1,949,062**	**680,403**

e. Gas Stations

	(1) Total sales (log)	(2) Chain store sales (log)	(3) 0-50km away sales (log)
Panel A: overall effect			
Pre-hurricane (-7,-6)	0.0007 (0.0128)	-0.0019 (0.0137)	0.0671 (0.0384)
Post-hurricane announcement (-5 to 15)	-0.0420** (0.0134)	-0.0499*** (0.0138)	0.0161 (0.0289)
Panel B: effect by stage			
Pre-hurricane (-7,-6)	0.0065 (0.0127)	0.0040 (0.0136)	0.0674 (0.0383)
Post-hurricane announcement (prep) (-5,-4,-3,-2,-1)	0.1005*** (0.0232)	0.0910*** (0.0236)	0.0668* (0.0316)
Hurricane (impact) (0 to 4)	-0.2295*** (0.0311)	-0.2435*** (0.0325)	-0.0170 (0.0371)
Post-hurricane (recovery) (5 to 15)	-0.0250** (0.0095)	-0.0292** (0.0099)	0.0090 (0.0313)
Merchant zip-code fixed effects	Yes	Yes	Yes
Date fixed effects	Yes	Yes	Yes
Observations	**2,793,147**	**2,499,474**	**979,213**